ULTRASONIC AMBIENT NOISE IN AUSTRALIAN SHALLOW WATERS AT FREQUENCIES UP TO 200 kHZ

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Douglas H. Cato and Michael J. Bell

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Abstract

Little is known of ambient noise in the ocean at frequencies above 50 kHz and there are few measurements above 20 kHz. The results of this study indicate that the sustained ambient noise at frequencies up to 200 kHz in temperate and tropical waters of depths less than about 60 m is characterized by the numerous sharp transient sounds of snapping shrimps. These transients have pulse widths of typically 3 to 8 μs (at one-third the peak voltage) and their bandwidth extends to well in excess of 200 kHz. Large variations in shrimp noise are to be expected over relatively short distances (hundreds of metres) as habitats change and hence shrimp numbers vary. Highest noise levels are to be expected near the bottom and where there are coral or rock outcrops, shells, sponges or debris to provide shelter for shrimps. Noise measured under these conditions exceeded a peak level of 140 dB re 1 μPa^2 at an average of about 20 pulses per second and exceeded 150 dB re 1 μPa^2 at an average of 3 to 4 pulses a second. Lowest noise levels have been observed over uncluttered mud or sand. Shrimp noise shows little diurnal or seasonal variation.

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Contents

Ultrasonic Ambient Noise in Australian Shallow Waters at Frequencies up to 200 kHz

1. *Introduction*

Ambient sea noise in the ocean has been extensively investigated at frequencies up to about 10 kHz, with some measurements to about 20 kHz and a few isolated measurements to about 60 kHz [1]. Very little is known about ambient noise at higher frequencies. This report discusses an investigation of the characteristics of ambient sea noise in shallow waters at ultrasonic frequencies up to 200 kHz, in the absence of rain (ultrasonic refers to sound at frequencies above the nominal upper limit of human audibility, i.e. 20 kHz). It is in response to a request to investigate the environmental noise relevant to the new minehunting sonar.

Available information suggests that a sustained background noise is to be expected in temperate and tropical waters of depth less than about 60 m from snapping (or pistol) shrimps (*Alpheus and Synalpheus* spp.), and this is supported by the results of this study. Noise from snapping shrimps was thoroughly investigated in the 1940s at frequencies below 10 to 20 kHz [2-4]. These studies suggested that shrimp noise would extend well above 20 kHz because of the shape of the measured spectra and the nature of the pulse generated by the shrimps. These papers also established the worldwide distribution of the shrimps. Widener [5] extended the measurements of shrimp noise to 50 kHz showing substantial noise levels up to this frequency, and commented that shrimp noise had components up to 150 kHz. The papers cited above generally showed that shrimp noise consisted of sharp impulsive clicks occurring in such large numbers that they produced a sustained background noise. In these measurements the pulse width of a single click appeared to be determined by the upper limit in the frequency response of the measuring equipment, suggesting that the pulse width might be shorter than measured and there might be significant energy at higher frequencies.

Other sources of ultrasonic noise are other biological sources (such as dolphins), breaking waves, rain on the sea surface and thermal agitation (the

noise of bombardment of the water molecules). The last of these provides the lower limit of ultrasonic noise levels. Theoretical estimates of thermal noise were made by Mellen [6] in 1952 and supported by laboratory measurements [7], but this component has yet to be measured in the ocean. Extrapolation of sea surface generated noise curves (see, for example, reference 8) suggests that thermal noise would be significant only at low wind speeds and frequencies above about 100 kHz. High noise levels have been measured from rain at frequencies up to 60 kHz [9-11], suggesting that this source would be significant at higher frequencies. Rain noise was not measured in this study, which was directed at sources of sustained ambient noise. However, it would be desirable to examine ultrasonic noise from rain in future work.

2. *Measurements*

Measurements were made at two locations:

(a) Noise was tape recorded at two positions off Cowley Beach on the Queensland coast near Innisfail, and later analysed on replay in the laboratory. Position A1 was in a water depth of about 6 m where coral and rock outcrops were evident. Position A2 was about 1 km away in 20 m water depth where the bottom consisted of muddy ooze. In both cases an ITC 1042 hydrophone was suspended about 2 m below a small boat. The signal was passed through a RANRL low noise preamplifier and recorded on a Teac tape recorder. The upper limit of the system response was limited by the hydrophone to 120 kHz.

(b) Noise was analysed directly from an ITC 1089 hydrophone laid on the bottom beside the wharf at MRL Sydney (at Pyrmont). The signal was passed through a low noise amplifier connected to a storage oscilloscope and a Data Precision Data 6000 high speed waveform analyser. The frequency response of this system extended to 350 kHz (- 3 dB point). Data were also recorded on the Teac tape recorder.

For the data from both locations, wave forms and spectra (Fast Fourier Transforms) from what appear to be individual shrimp snaps were obtained using the Data Precision Data 6000. Noise spectra averaged over many shrimp snaps were obtained using a Hewlett-Packard 3582A Analyser, by integrating over many Fourier Transforms. In this case it was necessary to use the recorded data, replaying at one-quarter of the record speed to transpose the data to the frequency range of the analyser. A white noise signal of known level was used as a calibration in the tape recordings.

3. Results

3.1 Characteristics of the Pulse from a Single Snap

The measurements of background noise showed the presence of high level pulses, examples of which are shown in Figure 1 (Sydney Harbour at Pyrmont) and Figure 2 (Coral Sea near Innisfail). Pulse widths measured at one third of the peak voltage (or pressure) varied from 3.5 to 8 μs. The noise of snapping shrimps at audio frequencies is well documented (see references cited above) and these pulses were recognisable as due to snapping shrimp, however the spectral measurements and pulse widths in this study showed that they contained significant energy up to frequencies beyond 100 kHz. The spectra of individual pulses are shown in Figures 3 and 4.

The pulses are characterized by a sharp rise in the direction of positive pressure followed by as rapid a fall. In Figure 2, the pulses show some negative overshoot that is not evident in Figure 1. This overshoot is probably an artefact of the tape recording process (the results of Figure 1 were analysed directly from the hydrophone preamplifier without tape recording). Direct recording results in an output on tape replay that is proportional to the time derivative of the input signal. Although the response of the replay amplifier compensates for the effect of this differentiation on the frequency response, it does not compensate for the phase distortion. As a consequence, the replay wave form resembles the rate of change of the input wave form, thus showing negative overshoot following decreasing pressure. There is some variation in the pulse shape at lower pressures, perhaps due to environmental effects, or the contribution of background noise. We have chosen the highest level pulses to display, but some interference from lower level pulses occurring in the same time scale is to be expected. We measured pulse widths of 3.5 to 8 μs (at one third the peak voltage) using the system with frequency response extending to 350 kHz (- 3 dB point). This appears to be a valid estimate of the pulse width, i.e. it was not determined by the bandwidth of the system. The system with response to 120 kHz showed pulse widths (at one-third the peak voltage) of 6 to 8 μs.

3.2 The Sustained Ambient Noise from Shrimps

Although individual shrimp snaps are very short in duration, they occur so frequently, because of the very high concentration of shrimps, that a sustained ambient background noise results. Estimates of the ambient background noise from shrimps, obtained by averaging the spectra over many pulses, are shown in Figure 5 for Sydney Harbour at Pyrmont and for position A1 in the Coral Sea near Innisfail. Also shown in Figure 5 for comparison are average surface generated noise spectra as a function of wind speed [8], which is usually the prevailing noise in the ocean. The sustained background noise from the shrimps at these positions is substantially higher than that expected from sea surface motion. Shrimp noise observed at position A2 in the Coral Sea was very much lower than at the two positions shown in Figure 5, and not sufficiently above background noise from other sources to make a reliable estimate of its spectral levels.

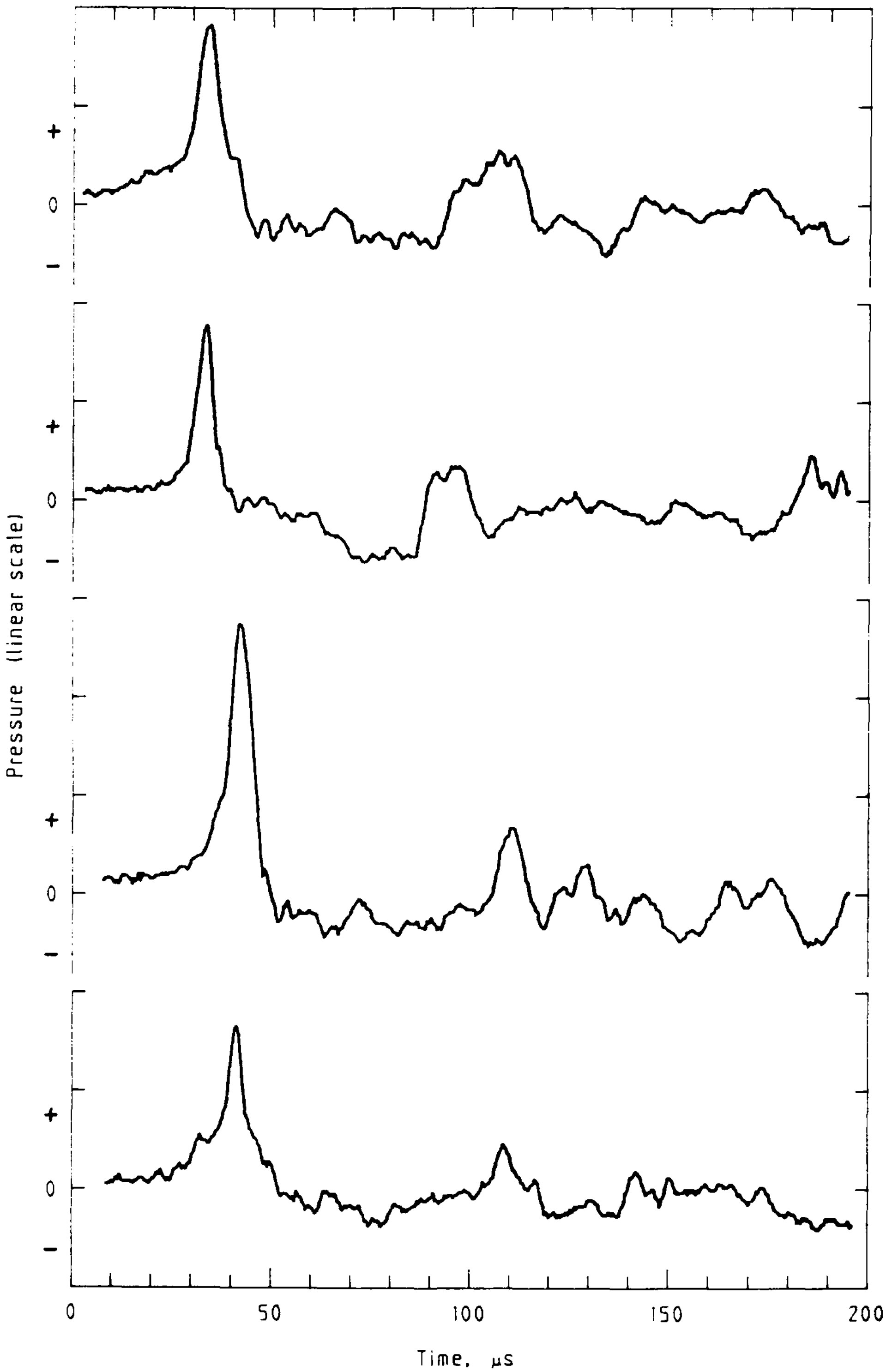

Figure 1: *Samples of the pressure wave form of the pulses from individual shrimp snaps, in Sydney Harbour at Pyrmont.*

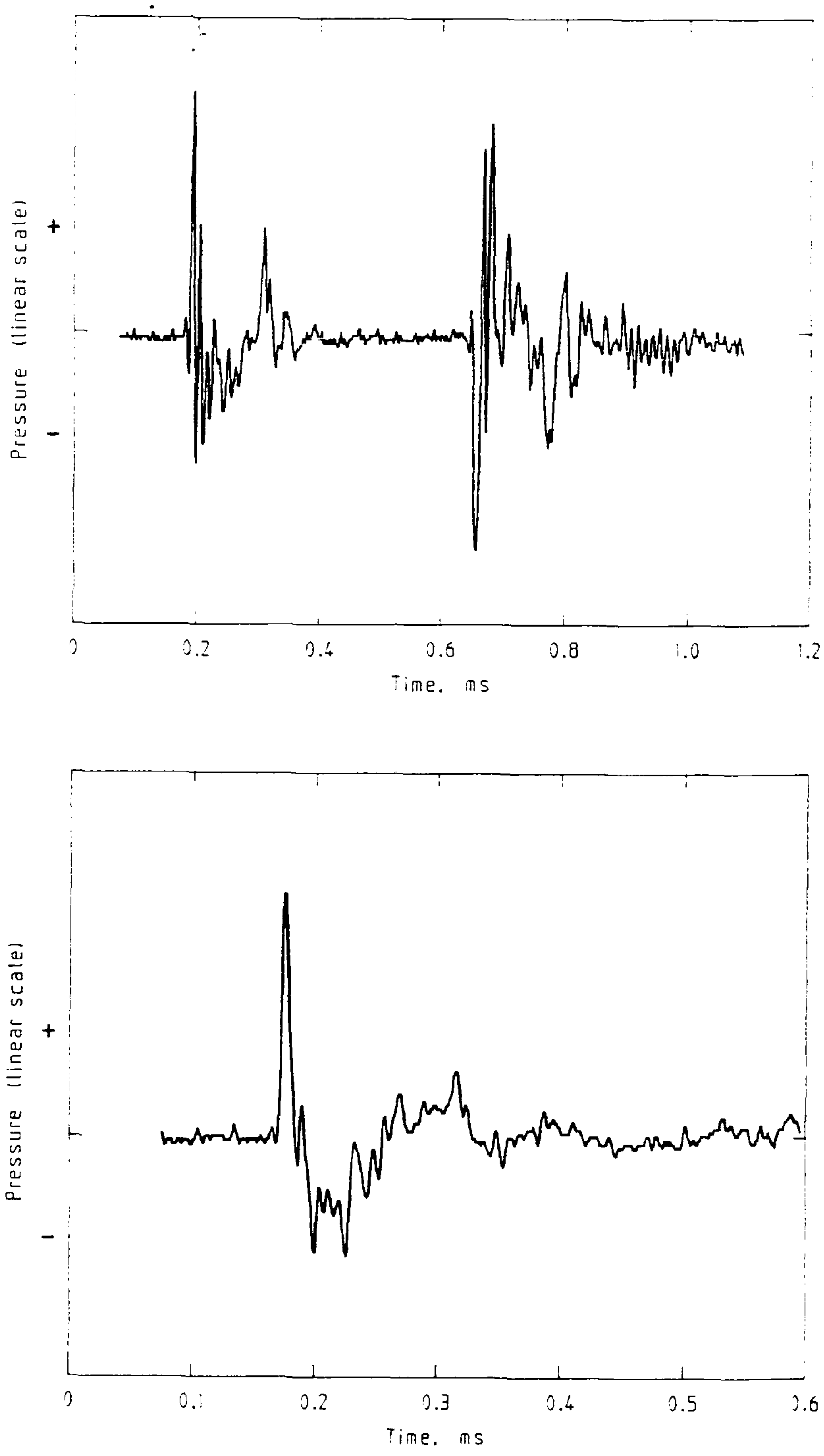

Figure 2: *Two examples of the pressure wave form of the pulse from a single shrimp snap, recorded at position A1 in the Coral Sea near Innisfail.*

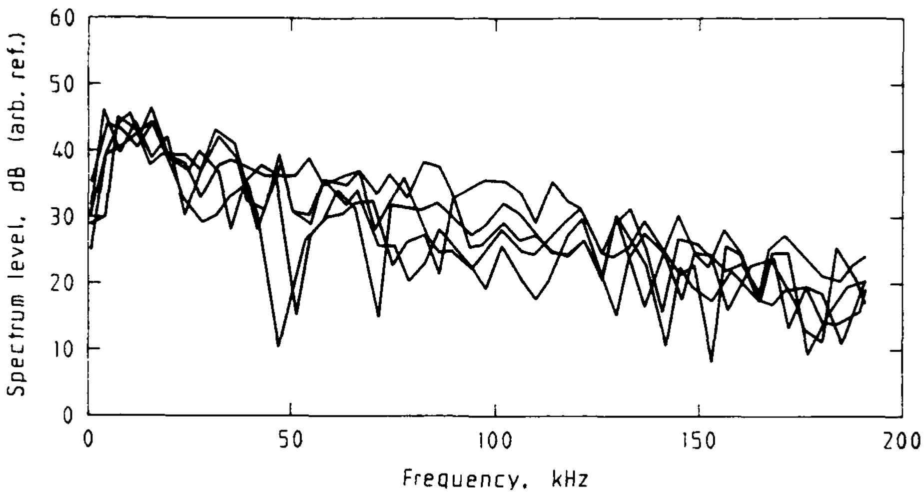

Figure 3: Overlay of several sample spectra of single shrimp snaps recorded in Sydney Harbour at Pyrmont. The wave forms for these particular snaps are shown in Figure 1.

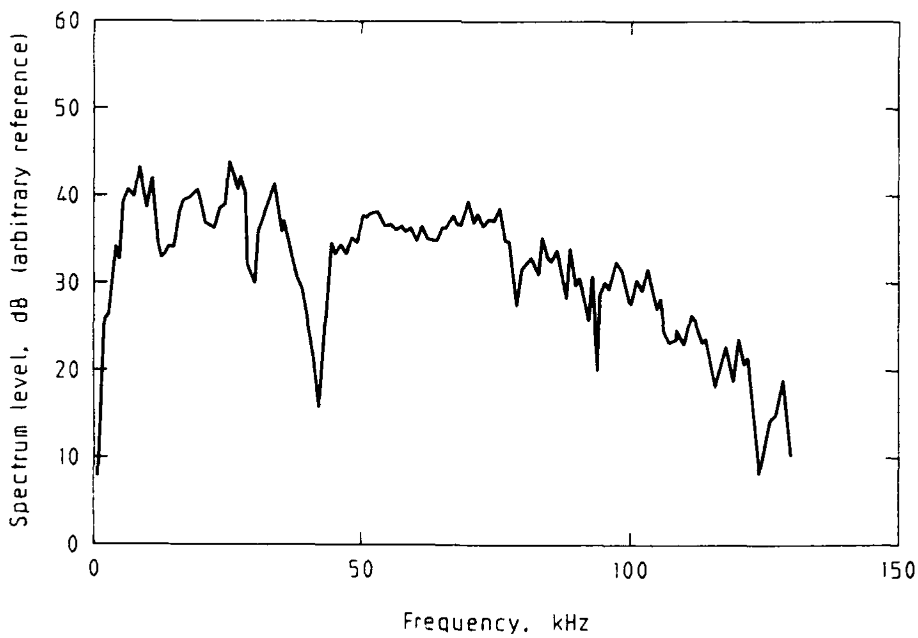

Figure 4: Typical spectrum of a single shrimp snap recorded at position A1 in the Coral Sea near Innisfail.

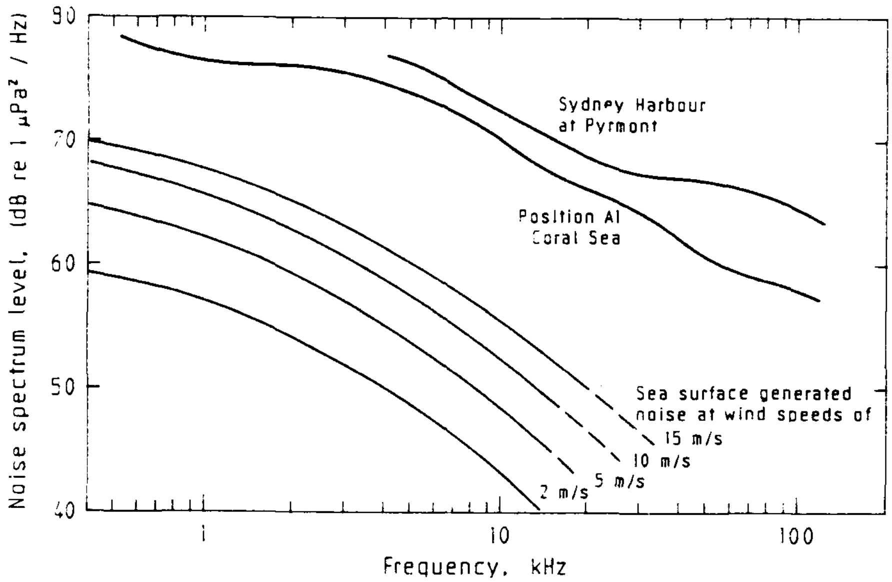

Figure 5: Time averaged spectra of the noise from snapping shrimps at two locations. Also shown are curves of surface generated (wind dependent) noise [8].

3.3 Distribution in Peak Level of the Pulses

The distributions of the peak levels of the observed pulses are given in Figure 6 which shows the average time interval between pulses exceeding specified levels. The results for Sydney Harbour at Pyrmont are comparable to those measured by Meuser [12] near Sydney. The results for the Coral Sea position A1 near Innisfail are similar to the others for levels up to about 145 dB re 1 μPa^2 (exceeded at intervals averaging about 130 ms) but beyond these values levels are lower for the same average time interval. The maximum peak levels observed were about 175 dB re 1 μPa^2 at Pyrmont and 160 dB re 1 μPa^2 at position A1 near Innisfail. The higher maximum peak levels at Pyrmont are probably the consequence of having the hydrophone on the bottom and thus significantly closer to the shrimps than at position A1.

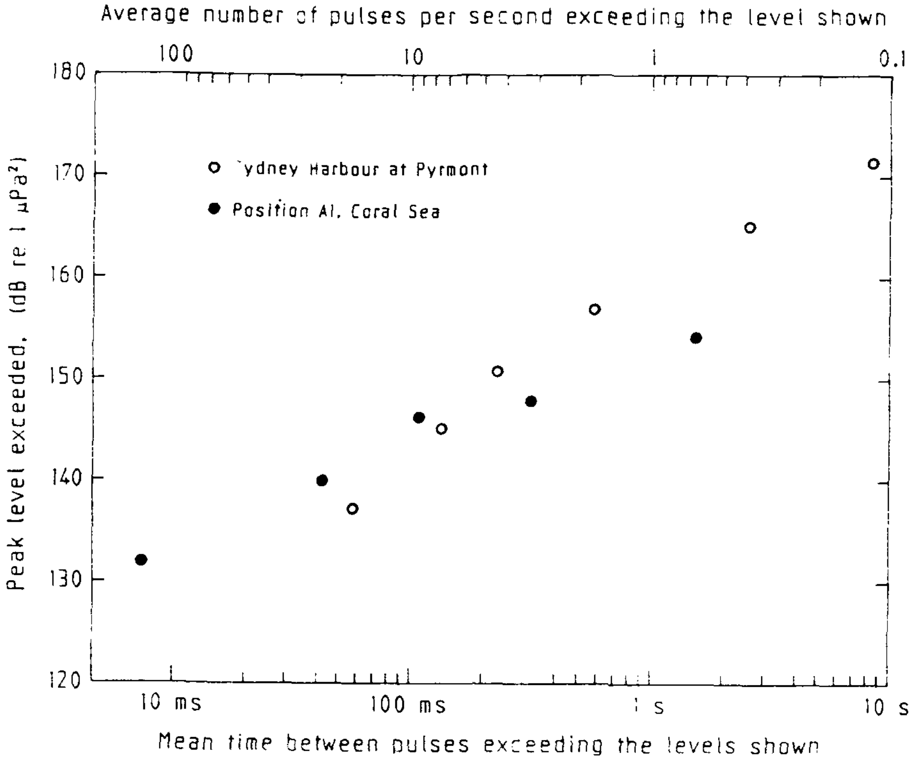

Figure 6: Distribution of the frequency of occurrence of shrimp pulses exceeding specified peak pressure levels.

4. Discussion

4.1 Aspects of Shrimp Biology Relevant to their Contribution to the Ambient Noise

4.1.1 Description

The snapping or pistol shrimp is a small shrimp of the genera *Alpheus* or *Synalpheus* in the family Alpheidae. It has disproportionally large claw or chela (Figure 7) which produces a sharp click when snapped closed. They are typically one to a few centimetres long, but some species may exceed 10 cm. The following summarizes factors of the biology that are relevant to sound production and the contribution to the background noise. It has been drawn mainly from the following sources:

(a) Knudsen Alford and Emling [2]: This gives details of many studies during the second world war relevant to sound production.

(b) Johnson, Everest and Young [3] and Everest, Young and Johnson [4]: These papers give details of sound production, biology and habitat, most of the data coming from the northern hemisphere, and with the emphasis on relevance to sound production.

(c) Banner and Banner [13-16]: They examined thousands of specimens of the genera *Alpheus* and *Synalpheus* from Australian waters in terms of the biology, habit and distribution. The specimens came from many different collections, usually with some indication of the conditions under which they were collected.

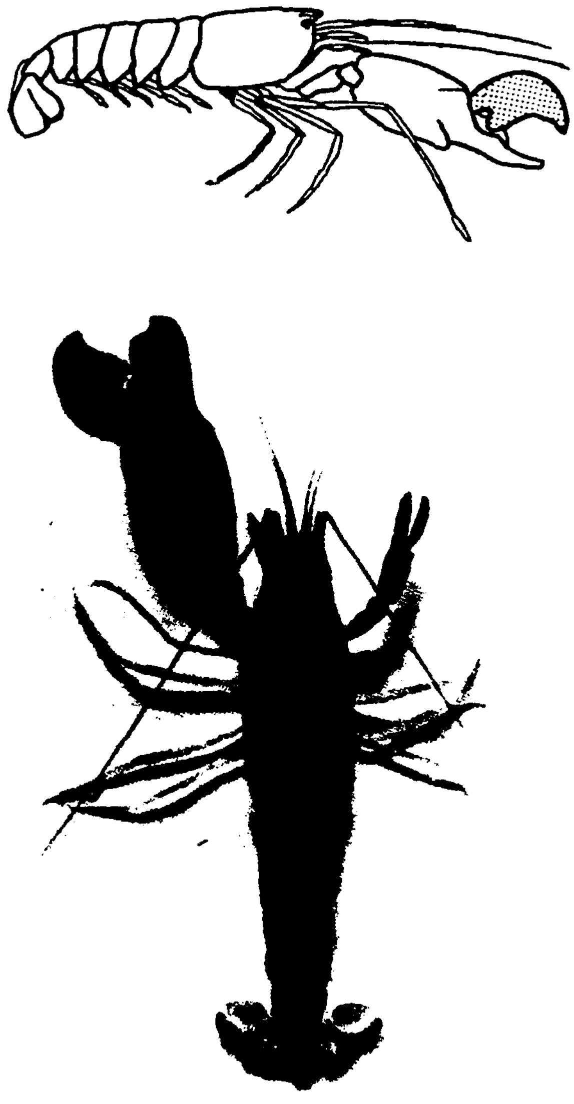

Figure 7: The snapping shrimp, about twice natural size. The photograph is from reference [3].

4.1.2 Sound Production

Sounds are produced by snapping closed the exceptionally large claw (chela) which may be more than half the length of the animal (Fig. 7). This claw has a hemispherical plunger on one side and a matching socket on the other. It is held open by suction pads and considerable muscular force is required to overcome the suction and close the claw. This forces the plunger into the socket at high speed, ejecting a fine jet of water, and producing the sharp impulsive click. Snapping appears to be used in aggression and defence [3], and also to stun prey [17]. Shrimps are usually concentrated in such large numbers that there is continual snapping, so that the sounds provide a continuous crackling background noise. Although there are hundreds of species of snapping shrimp, and many are to be found in Australian waters, sound production generally follows this pattern.

4.1.3 Habitat

Snapping shrimps are said to be "cryptic", that is, they usually lie hidden in or under objects that provide some shelter such as bottom debris, rocks, shells, corals, sponges, etc., and some burrow into the substrate. Because they seek concealment, they are difficult to find and are far more abundant than appearances would indicate. A biologist working on the Great Barrier Reef commented that large numbers of shrimps may be found in the pores of one sponge [18].

Because of the variation in conditions on the bottom, the numbers and hence their contribution to the background noise may vary substantially over distances of tens to hundreds of metres. For example, outcrops of rock or coral or small depressions where debris may collect may be only small in scale but provide much larger concentrations of shrimps than in the surrounding areas. We have observed substantial variation in shrimp noise while listening from a drifting boat as it passed over different bottom conditions. Higher noise levels tend to be observed where there are rock or coral outcrops than over mud or sand. Areas which local fishermen refer to as "reefs" are usually much noisier than surrounding areas. Such reefs are concentrations of rocky outcrops, debris, etc. favourable to fish and shrimp habitation.

Johnson, Everest and Young [3] measured variation in noise level of up to 30 dB in traverses across varying bottom conditions in the San Diego area, the greatest rate of variation being about 10 dB change over a distance of 500 m. Highest noise levels were observed where the bottom was rock, and lowest levels over mud and sand, and in deeper water (see Fig. 8).

The trend to lower levels over mud may not apply in estuarine waters, since some species prefer estuarine mudflats and seagrass beds, where they burrow into the mud. The species *Alpheus edwardsii*, for example is common in New South Wales estuaries [15].

4.1.4 Geographical Distribution

Banner and Banner [13] note that "The alpheids are characteristically associated with the complex of tropical coral reefs, from the inshore beaches across the

growing reefs to the offshore muddy bottoms. There appears to be a greater penetration of the family into temperate waters in Australia than in the Northern Hemisphere." Two factors appear to govern the broad scale geographical distribution of snapping shrimps: water temperature and depth. The temperature dependence is complex, but as a rule of thumb, a winter temperature of 11°C can be considered the minimum tolerable [3]. This corresponds on average to a latitude of about 40° with some variation depending on local current directions. The expected world wide distribution is shown in Figure 9 [3]. The depth limitation is summarized by Johnson, Everest and Young [3] from data from a number of sources. This shows that most shrimp are to be found in water depths of less than about 60 m, the concentrations dredged or trawled from greater depths being only about a quarter of those found in less than 60 m. Very few were found in waters deeper than 130 m, though some have been found in waters as deep as 450 m. Noise measurements have confirmed that highest levels occur in water depths of less than 60 m.

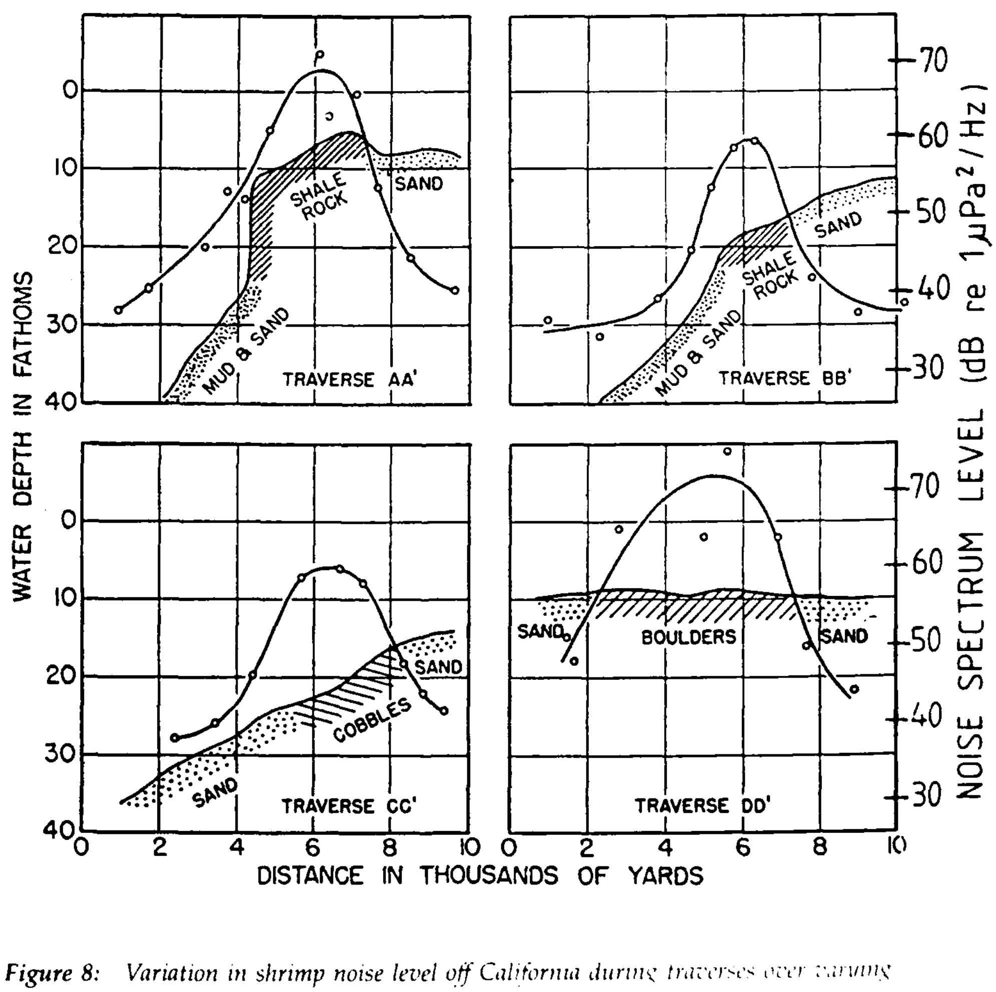

Figure 8: Variation in shrimp noise level off California during traverses over varying bottom conditions and depths (from reference 2).

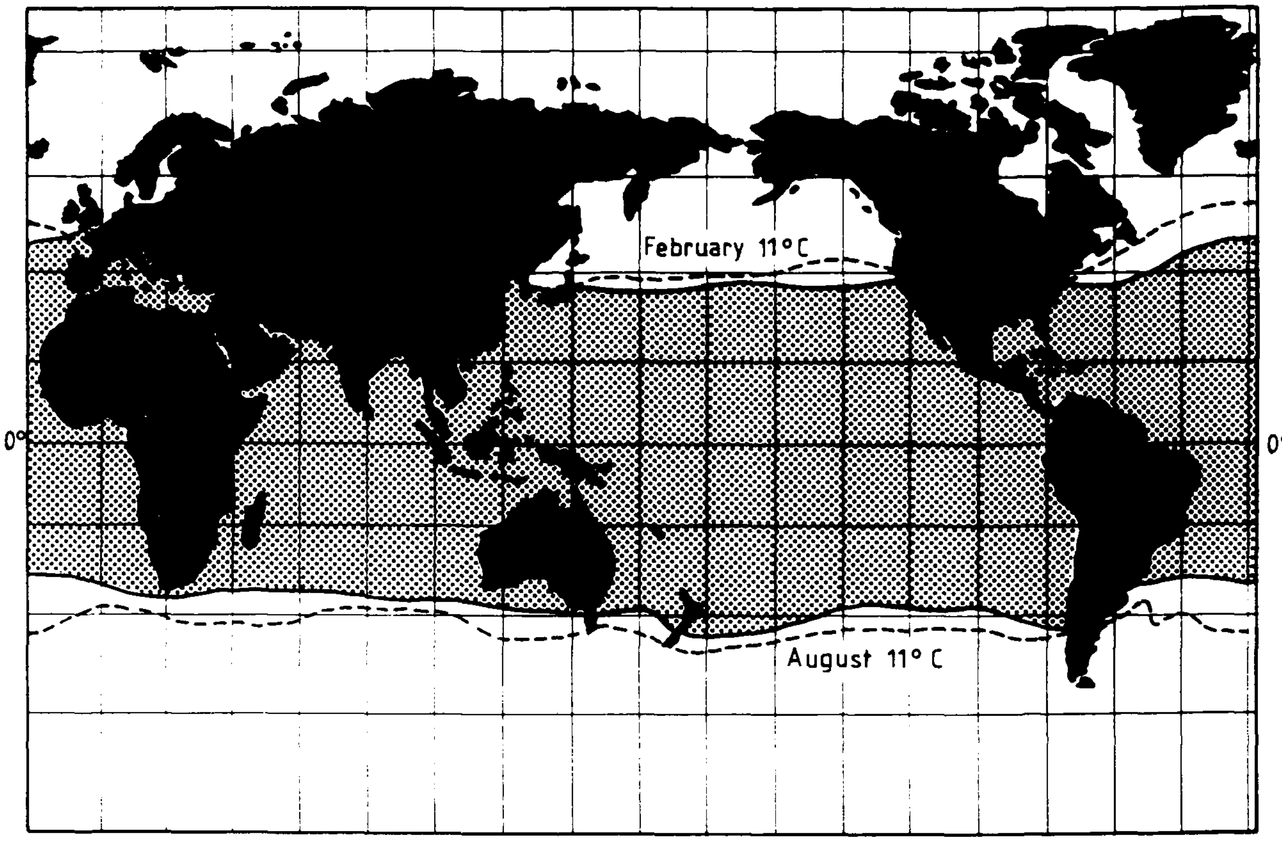

Figure 9: World wide distribution of snapping shrimp according to reference 3. They are to be found in the shaded area where bottom conditions are suitable. Highest concentrations are in depths of less than about 60 m.

The work by Banner and Banner [13-16] in the Australian region shows similar trends. Although some species have been found only in a few locations and some others are limited to tropical waters, many species have been found widely distributed off east and west coasts of Australia as well as in tropical waters. Some species are noted to occur off all coasts of Australia. Recordings of ambient noise (generally limited to frequencies below 20 kHz) in Australian waters have generally shown significant shrimp noise in shallow waters except for the only known recordings off Victoria: in the harbour at Portland and off Warnambool where shrimp noise was sporadic and of relatively low level when evident. The recordings off Victoria are, however, only a few short samples and may not be representative. The 11°C winter isotherm runs south of Tasmania, and since shrimps have been noted to occur "off all coasts of Australia" it is suggested that, in the absence of further data, shrimp noise should be expected off all coasts. Recordings as far south as Perth and Jervis

Bay, show shrimp noise to be as dominant as in tropical waters. Figure 10 shows the incidence of shrimp noise at positions where sea noise has been recorded around Australia in water depths less than about 60 m.

In Australian waters, specimens have been found in water depths up to 150 m but most were obtained in waters less than the 60 m, as also found in other parts of the world. In Australia there is significant penetration of rivers and estuaries where the water is brackish, specimens having been found in the Swan River, and rivers of New South Wales and Queensland.

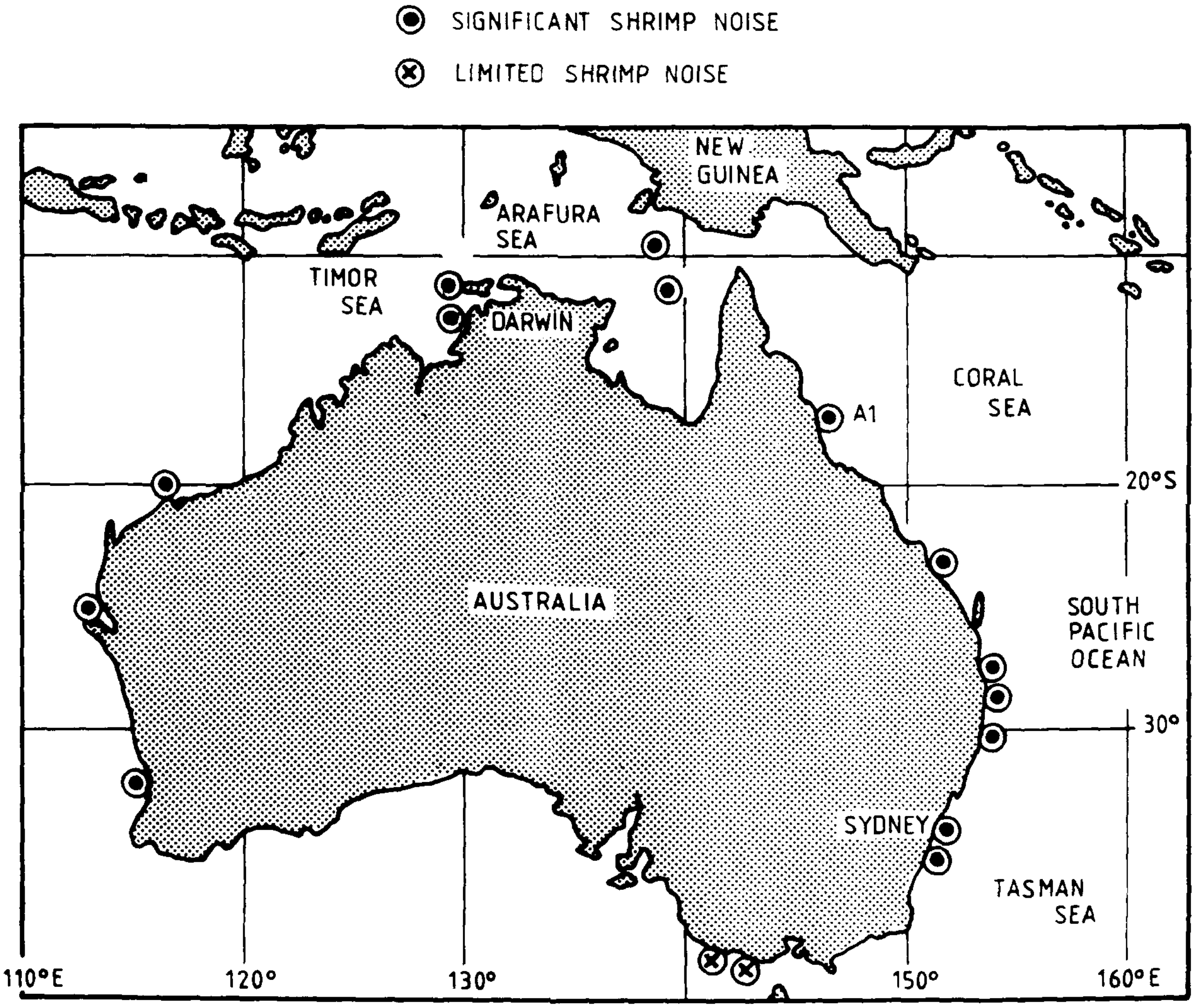

Figure 10: Positions where noise has been recorded around Australia in water depths of less than 60 m. Apart from the measurements at position A1 in the Coral Sea (described in this report) the upper frequency limit of recording was between 10 and 20 kHz. In addition, recordings have been made in Moreton Bay, Pittwater (Sydney), various parts of Sydney Harbour, and Jervis Bay, also limited in frequency response, except for the recordings in Sydney Harbour described in the text. All showed high levels of shrimp noise.

These results suggest that shrimp noise should be expected in all waters near Australia at positions in or near water depths of less than 60 m. No evidence of variation with latitude has been detected for latitudes of 35° S or less.

4.2 Characteristics of Shrimp Noise

4.2.1 Characteristics of Individual Shrimp Snaps

The measurements using our system with the 350 kHz bandwidth show that the pulse width of an individual snap varies from 3.5 to 8 μs width (at one-third of the peak voltage). These are probably the first measurements of adequate bandwidth to show the true nature of the pulse of a single shrimp snap. Inadequate bandwidth would broaden the pulse. Meuser [12] presents measurements of "strong pulse like disturbances" during trials in HMAS Rushcutter near Sydney. He suspected that these were from snapping shrimps, based on information on biological noise given by Urick [19]. In his Figure 3.3 he shows some examples of pulses recorded with a system frequency response to 150 kHz. The pulse widths (measured at one-third the peak voltage) varied from 5 to 8 μs. Everest, Young and Johnson [4] show a single shrimp snap pulse recorded with a system response extending to 50 kHz. The pulse is so narrow in the diagram that it is difficult to measure the width accurately, but it appears to be about 10 μs.

Everest, Young and Johnson [4] measured the source level of snapping shrimps off California to be on average 146 dB re 1 μPa^2 at 1 m (peak level) with occasional values as high as 160 dB re 1 μPa^2 at 1 m. Their measuring bandwidth was 50 kHz. It is estimated that extending the bandwidth beyond 100 kHz is unlikely to increase the peak level by more than 2 to 3 dB given the rate at which the spectrum falls with frequency. The highest levels measured at Pyrmont would therefore be about 12 dB above this upper estimate of source level. A shrimp having this source level would need to be about 0.25 m from the hydrophone at Pyrmont to produce the highest levels observed. This could well have been the case, but of course there may well be significant variation in source levels between species and between individuals. The highest peak levels of 160 dB re 1 μPa^2 measured at position A1 near Innisfail would suggest that source levels may be higher than this level, since the hydrophone was about 4 m from the bottom, assuming that no shrimps were above the bottom.

It seems likely that the maximum peak levels observed with a near surface hydrophone will decrease with increasing water depth, since the shrimp are to be found predominantly on the bottom (see section 4.1.3). A rough estimate based on our measurements would suggest maximum peak levels for a shallow hydrophone would be about 150 dB re 1 μPa^2 for a water depth of 20 m, 145 for 30 m and about 140 dB for 60 m. It should be recognized, however, that there is considerable uncertainty in the absolute values of these estimates, given the uncertainty in the actual distances of the sources in our measurements and the possibility that source levels may vary significantly. The variation in level with depth should be a more reliable estimate and note that these estimates apply only over shrimp beds. We can also expect that the levels exceeded for specified mean times between pulses, as shown in Figure 6, would decrease with increasing water depth, the change being greatest for the higher levels and longer time intervals. The values would tend to converge for the lower levels

and short time intervals, since these are determined by sources at longer ranges whether or not the hydrophone is in or above the shrimp bed.

There is some evidence that the rate of occurrence of pulses from snapping shrimps is not random. In observing the higher level pulses, it was noted that they tended to occur in bursts, as though the first pulse triggered several other pulses. Snapping by shrimps is thought to be an act of aggression or defence (section 4.1.2). For an individual shrimp, survival could be enhanced by snapping, not only when an aggressor is directly sensed by that individual, but also when nearby shrimps are threatened. Such a preemptive snap could well influence subsequent movements of the aggressor. One snap may therefore trigger others from individuals in close proximity.

4.2.2 Sustained Ambient Noise from Shrimps and the Variation with Position

From the discussion of the habitat of snapping shrimps in section 4.1.3, it will be seen that concentrations of shrimps may vary substantially over relatively short distances (hundreds of metres or even tens of metres). Thus average and maximum noise levels will vary accordingly. Figure 8, reproduced from Johnson, Everest and Young [3] shows how noise spectrum levels at 10 to 20 kHz varied in traverses over shrimp beds. Here the shrimp were concentrated in the areas where there were boulders, shale or cobbles.

We observed a substantial variation in noise level between positions A1 and A2 near Innisfail. Position A1 was very favourable to shrimp habitation with rock and coral outcrops, large coral and shell fragments and gave the high noise levels discussed above. Position A2, depth 20 m, was about 1 km away from A1 and bottom conditions were reported by divers to be muddy ooze with no rock or coral. These conditions are less favourable to snapping shrimp (see section 4.1.3). Although some snapping shrimp noise was observed at this position, it was very much lower than at position A1 and was not sufficiently above background noise to make reliable estimates of the noise levels. The background noise was higher than usual because it was dominated by splashing of waves on the boat in the short choppy sea at the time.

An idea of the range of variation of shrimp noise with different positions is shown by the time averaged spectra of Figure 11. Although some of the measurements shown are limited to frequencies of 10 kHz or 50 kHz, the trend of their spectra at higher frequencies can be estimated by comparison with the wide band spectral measurements also shown. The Timor Sea data are from references 20 and 21. The data of Widener [5] were recorded at various positions in shallow water off Florida with a hydrophone on the bottom. The highest curve was recorded at a pier in water of only 3 m depth with the hydrophone among a high concentration of shrimps. This curve therefore represents an extreme. The lowest of the three curves marked "Widener" shows the lowest levels of shrimp noise in his measurements. The remaining curve is typical of his measurements from a boat (actual positions and depths not given). In the measurements at position A1 the hydrophone was suspended at about mid depth, so these results are more typical of noise in waters of high shrimp concentration. Also shown for comparison are the generalized surface generated noise curves [8] and the range of rain noise [9, 10]. Thermal noise is estimated to be about 25 dB re 1 $\mu Pa^2/Hz$ at 100 kHz.

rising with frequency at the rate of 6 dB per octave [6]. Thermal noise levels are therefore too low to appear on the graph of Figure 11, and would be significant only at frequencies above about 100 kHz at low wind speeds in the absence of shrimps and rain.

Figure 11 shows that levels of sustained shrimp noise may vary by as much as 30 dB. Peak levels of pulses may vary over a greater range.

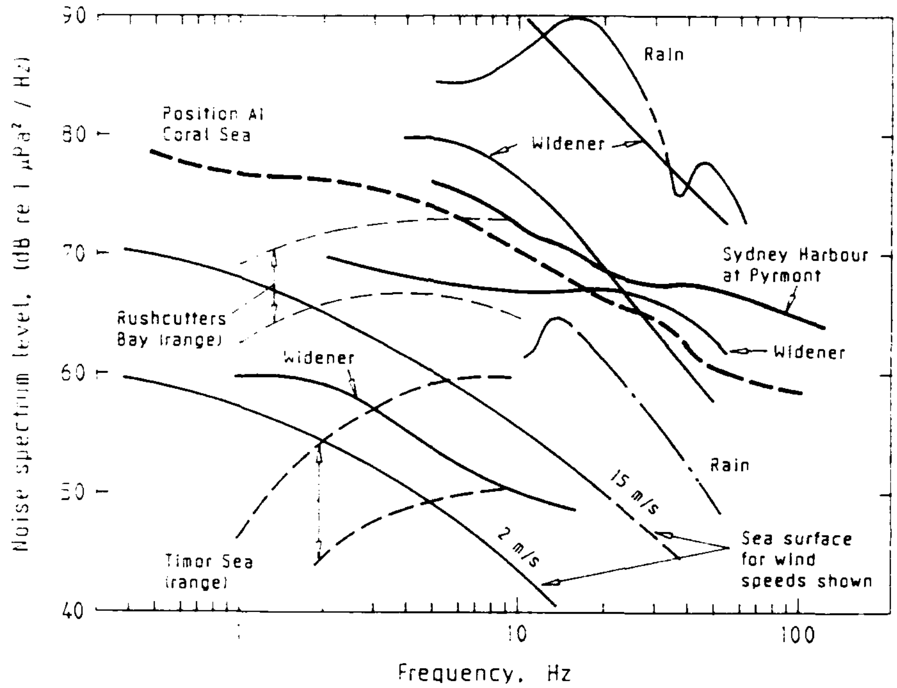

Figure 11: Comparison of time averaged snapping shrimp noise spectra at various locations. The measurements by Widener [5] were off Florida with a bottomed hydrophone. The highest curve was recorded in 3 m of water in a high shrimp concentration so is atypical. Spectra of surface generated noise [8] and rain noise [9, 10] are also shown. The rain noise precipitation rate was 1.2 mm/h for the lower curve [10] and 260 mm/h for the upper curve [9].

4.2.3 *Temporal Variation of Shrimp Noise*

Data on the temporal variation of snapping shrimp noise are available only at frequencies below 20 kHz, but it is expected that levels at higher frequencies would be correlated with those at lower frequencies. In the northern Pacific Ocean, variation of up to 8 dB over the course of a day has been observed with levels at night being higher than that during the day, and with maximum levels just before sunrise and just after sunset [2, 4]. No seasonal variation was

observed in these studies. Long term measurements in 35 m water depth in the Timor Sea in April, July and October showed an overall variation of about 10 dB in the shrimp noise level, but there was no consistent diurnal pattern to the variation in noise level [20, 21]. There was some evidence, however, that levels were generally lower in October than in July and April by a few decibels. Even at the lowest levels, it formed the prevailing ambient noise above about 2 kHz. Snapping shrimp noise is audible in Sydney Harbour throughout the year.

Shrimp noise recordings in Australian waters have been made in all seasons and at various times of day. No temporal variations in excess of 10 dB have been observed at any location. This appears to be consistent with observations in other parts of the world. The available data suggests that it is characteristic of snapping shrimp noise to continue unabated day and night throughout the year with only small variations in level at any one position.

4.3 Other Sources of Ultrasonic Noise

4.3.1 Rain Noise

Rain noise has been measured at frequencies up to 50 kHz by Scrimger *et al.* [10, 11], and to 60 kHz by Nystuen [9]. The measurements by Scrimger *et al.* show noise levels of between 35 and 50 dB re 1 $\mu Pa^2/Hz$ at 50 kHz for precipitation rates from 0.2 to 1.2 mm/h (light rain). Their spectrum for 1.2 mm/h is shown in Figure 11. Nystuen's results show levels between 58 and 74 dB re 1 $\mu Pa^2/Hz$ at 60 kHz for very heavy rain, the highest levels corresponding to an extreme precipitation rate of 260 mm/h. The highest noise levels from this set of measurements are also shown in Figure 11. There is some uncertainty in their results above 50 kHz because of uncertainty in the directional sensitivity of the hydrophone at these frequencies. It is apparent that rain is an important source of noise at ultrasonic frequencies. The spectral shapes suggest that rain noise levels would decrease with increasing frequency beyond the upper limit of the measurements. However, it is probably not safe to assume this in view of the complexity of the spectral shape at lower frequencies. Rain noise results predominantly from oscillation of bubbles of air entrained as drops pass through the surface, rather than from the impact of the drop on the surface [22]. Drops entrain air only for a certain range of drop diameters and impact velocities (see Fig. 8 of Reference 22), and this range varies with impact angle which is dependent on wind speed. As a consequence, there is no simple dependence of rain noise on precipitation rate, even though noise levels will generally increase with precipitation rate. A usable relationship to predict noise levels as a function of the above parameters has yet to be determined.

4.3.2 Ultrasonic Pulses from Dolphins

Although snapping shrimp provide the sustained background noise in shallow water a sporadic contribution can be expected from dolphins, possibly at much higher levels. Dolphins produce intense broad band clicks for the purpose of

echo-location (active sonar). These clicks are similar in some respects to those of snapping shrimps, but source levels are up to 70 dB higher.

The best documented examples are for the bottle nose dolphin *Tursiops truncatus* which is common in coastal waters of Australia. Measurements of animals in Hawaiian waters [23, 24] have shown that the clicks are very short in duration with a pulse width (at one-third peak level) of about 5 µs, similar to that of snapping shrimp. The energy in a click extends to 200 kHz, with highest levels in the range 100 to 150 kHz. The emitted sound is concentrated in a beam of width 10° vertically and horizontally (- 3 dB points). Source levels in the beam are about 220 dB re 1 μPa^2 at 1 m (peak to peak). Using an absorption attenuation of 27 to 35 dB per km over the frequency range 100 to 150 kHz [25], and assuming spherical spreading propagation loss, we calculate that a hydrophone in the beam of a dolphin at a range of 500 m would receive peak sound levels of about 150 dB re 1 μPa^2, similar to some of the higher levels observed for individual snaps of snapping shrimps. However the level falls sharply outside the beam. For example, at 30° off the centre of the beam, the dolphin would need to be less than 70 m from the hydrophone to produce these levels.

Dolphins are nomadic and many orders of magnitude less concentrated than snapping shrimps, their numbers being many orders of magnitude less. For these reasons, and given the narrowness of their beam, their contribution to the background noise in the region of 100 kHz is likely to be a sporadic one, occurring as a school passes by. They are, however, inquisitive and may direct their sonar beam directly at objects like hydrophones and transducers, and very high level pulses are to be expected under these conditions.

5. *Conclusions*

In the frequency band 20 kHz to 200 kHz, the prevailing background noise around Australia in water depths of less than about 60 m is due to snapping shrimp, of which there are many species of the genera *Alpheus* and *Synalpheus*. These animals occur in such large numbers that the continual snapping of the disproportionately large claw produces a sustained background noise. Each snap is a sharp pulse typically 3.5 to 8 µs wide (measured at one-third the peak pressure). The source level appears to lie somewhere in the range 145 to 170 dB re 1 μPa^2 at 1 m (peak level), probably varying between species and individuals. In high noise conditions, i.e. with a hydrophone over a large concentration of shrimps, a peak level of 140 dB re 1 μPa^2 is exceeded 20 times per second and 150 dB re 1 μPa^2 3 to 4 times per second. These levels would decrease as the distance of the receiver from the shrimps is increased, as would happen for a receiver near the surface in deeper water. There is some evidence that the higher level pulses occur in bursts. The shrimp noise spectrum extends to beyond 200 kHz.

Snapping shrimp generally hide in cavities in rock, coral or debris and concentrations vary substantially over relatively small distances (i.e. hundreds of metres) as bottom conditions change. Variations in noise level of 10 dB over 500 m have been observed. Variations in water depth and habitat produce variations in excess of 30 dB in the shrimp noise. At sea, highest noise levels can be expected where the bottom provides concealment by rock, coral or other

debris, and lowest levels where the bottom is mud or sand. This may not be the case in estuaries, however, since there are species that prefer mudflats and seagrass beds, where they burrow into the mud.

Snapping shrimp noise can be expected in all coastal waters around Australia. It may be diminished in areas furthest south like the coast of Victoria or Tasmania, but too few measurements have been made to comment with any certainty. Most measurements have been in latitudes of 35° S or less, and have shown that shrimp noise prevails with no apparent dependence on latitude within this range. High levels of shrimp noise have been observed in bays and harbours.

As far as can be determined, shrimp noise persists day and night throughout the year with little variation. No consistent diurnal variation has been observed in the Australian region, although several decibels change has been observed elsewhere. Some small variation has been observed with season.

Rain causes high levels of noise at ultrasonic frequencies. Reported measurements are limited to frequencies below 60 kHz, and although spectra decrease with frequency as this limit is approached, it seems likely that rain will contribute significantly to the ambient noise well beyond 60 kHz. Highest levels of rain noise are comparable to the highest levels of shrimp noise. It is therefore an important, though intermittent source of ultrasonic noise, and further studies are warranted.

Dolphins, which are common in Australian coastal waters produce intense pulses similar to those of shrimps, with energy extending to 200 kHz. They may contribute sporadically to the ambient noise as schools pass by.

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25. Reference 19, p. 109, Figure 5.5.

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ABSTRACT

Little is known of ambient noise in the ocean at frequencies above 50 kHz and there are few measurements above 20 kHz. The results of this study indicate that the sustained ambient noise at frequencies up to 200 kHz in temperate and tropical waters of depths less than about 60 m is characterized by the numerous sharp transient sounds of snapping shrimps. These transients have pulse widths of typically 3 to 8 us (at one-third the peak voltage) and their bandwidth extends to well in excess of 200 kHz. Large variations in shrimp noise are to be expected over relatively short distances (hundreds of metres) as habitats change and hence shrimp numbers vary. Highest noise levels are to be expected near the bottom and where there are coral or rock outcrops, shells, sponges or debris to provide shelter for shrimps. Noise measured under these conditions exceeded a peak level of 140 dB re 1 μPa^2 at an average of about 20 pulses per second and exceeded 150 dB re 1 μPa^2 at an average of 3 to 4 pulses a second. Lowest noise levels have been observed over uncluttered mud or sand. Shrimp noise shows little diurnal or seasonal variation.

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